ESSSA Industry Day Tour

Engineering , Science Services &
Skills Augmentation
(ESSSA)

Industry Day Tour Package
May 23, 2011

ESSSA Industry Day Tour

Tour Instructions

- Please obtain a copy of the tour guide booklet
- ABSOLUTELY no questions will be answered during the tour
- Questions may be written down and submitted via electronic mail to emeterio.v.hernandez@nasa.gov no later than May 31, 2011, 4:30 p.m., CST
- No picture taking or recordings are allowed
- Please leave cameras and cell phones on the bus (leave on your seat or place in provided basket. The Bus will be locked)
- No restroom facilities will be accessible during the tour
- Do not break away from group for any reason
- **Anyone violating the above rules will be escorted off of the center**

ESSSA Industry Day Tour

Materials and Processes Laboratory

Building 4612

Analytical and Environmental Chemistry
Materials Diagnostics Laboratory
Materials Mechanical Test Facility (MMTF)

Analytical and Environmental Chemistry

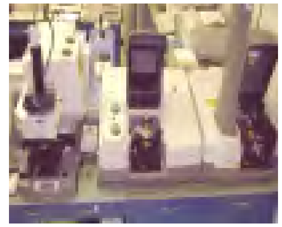
Analytical Laboratories

The General Instrumentation and Inorganic Chemistry Laboratories house a variety of specialized instruments that allow development of new tests to characterize candidate materials and chemicals. The work of these chemistry laboratories is supported by a complement of accurate weights and measures, which are vital to the determination of properties of materials.

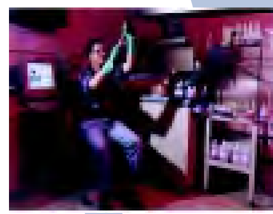
The ***Inorganic Chemistry Analysis Laboratory*** supports analyses of materials using standard gravimetric, titrimetric, precipitation, and calorimetric procedures.

The ***Ultraviolet/Visible Spectrophotometry Laboratory*** is used for analysis of thin films and organic materials in water.

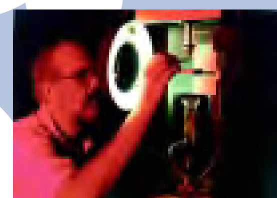
In the ***Mass Spectrometry Laboratory***, gases are analyzed for their chemical composition in support of cryogens and fuels used in propulsion technology.



The ***Infrared Spectroscopy Laboratory*** supports a variety of NASA programs with the identification of chemical contaminants. Instrumentation includes bench and microscopic infrared spectrometers, a Raman spectrometer, and a coupled thermogravimetric-infrared analyzer for thermal/chemical decomposition studies.



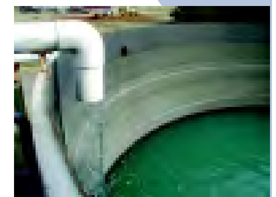
The ***Inductively Coupled Plasma Emission Spectroscopy Laboratory*** analyzes multi-element samples to determine their composition. Elements can be detected in low parts-per-billion concentrations.



Thermal Analysis Laboratory instruments determine the heat associated with chemical changes and stresses.

The ***X-Ray Fluorescence and Diffraction Laboratory*** supports analysis of the composition and determination of the crystalline structures of metals and alloys.

Environmental Chemistry Laboratory



This laboratory ensures that the air, water, and soil around MSFC are uncontaminated, to provide an environmentally safe work place. The laboratory monitors 13 National Pollution Discharge Elimination System sites for various environmental pollutants and is certified to analyze drinking water by the Alabama Department of Environmental Management.

The laboratory's ***Ion Chromatograph*** is used to determine non-metal species in aqueous media for waste-water quality control, while the ***Gas Chromatograph/Mass Spectrometer*** identifies volatile organic compounds. A ***High Pressure Liquid Chromatograph*** is used for polynuclear aromatic hydrocarbon analyses.

Web Sites

Chemistry Group
http://ims-1.msfc.nasa.gov/IDS/Projects/Projects_D-F/EDxx/ED30/ED36/index.html

Materials, Processes, and Manufacturing Department
http://map.msfc.nasa.gov/

Marshall Space Flight Center
http://www1.msfc.nasa.gov/

NASA
http://www.nasa.gov/

Working with the Technical Community

MSFC Analytical & Environmental Chemistry personnel are customer-oriented and ready to perform any specialized testing that a customer might require.

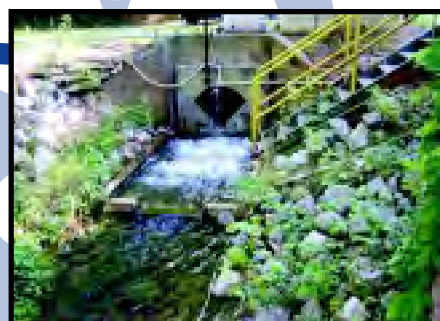
Contact the Team Leader of the Analytical & Environmental Chemistry Team at Marshall Space Flight Center to learn how we can meet your materials information needs.

Contacts

Materials, Processes, and Manufacturing
Department/ED36
Building 4612
Marshall Space Flight Center
Huntsville, AL 35812

Chemical Laboratory Locations

MCRF



Contamination Control

MP&M Laboratories

Pub 8-40082

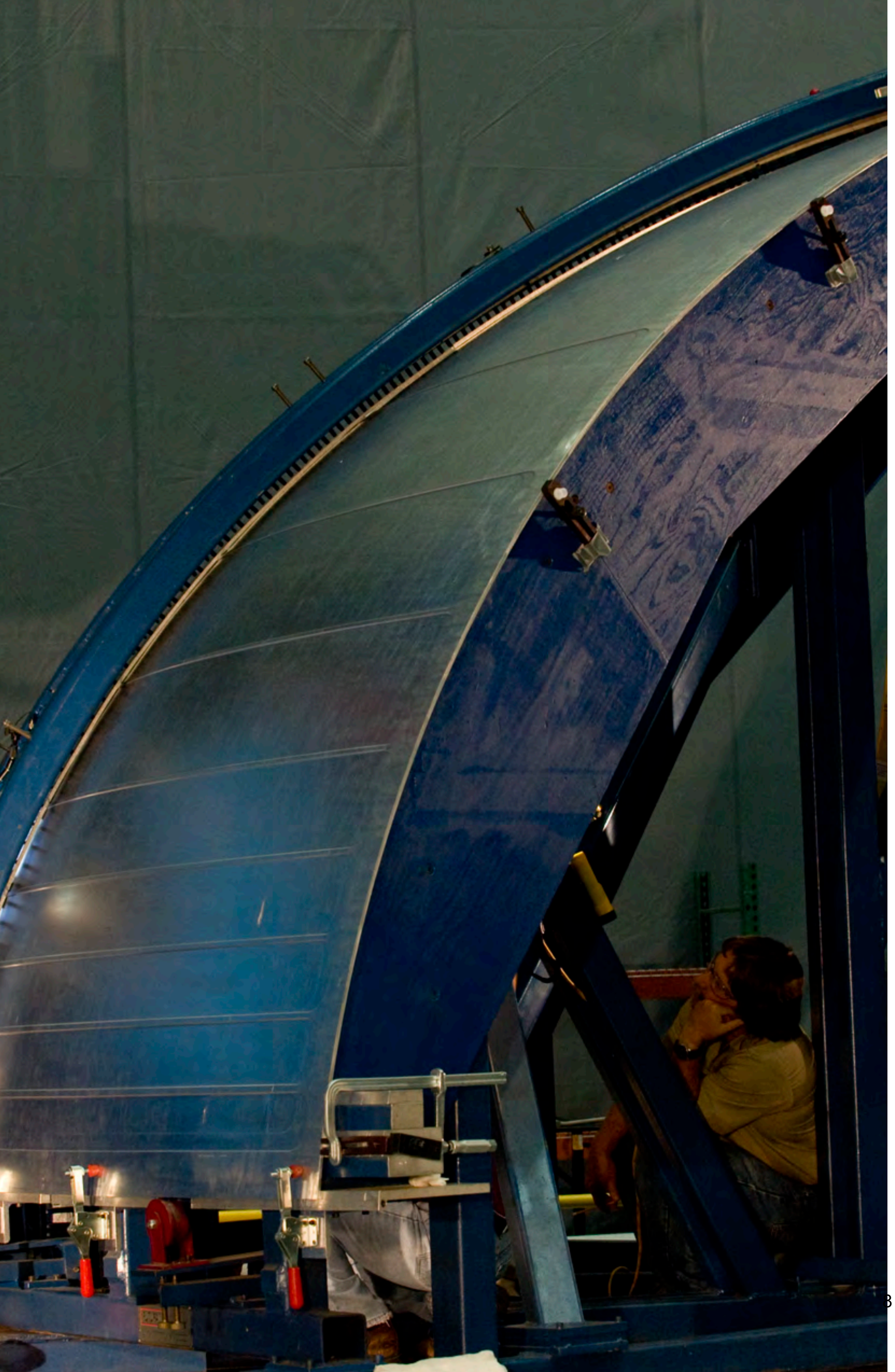
Marshall Space Flight Center

Analytical & Environmental Chemistry Laboratories

With its comprehensive and complementary materials test capabilities, the Analytical & Environmental Chemistry Team at Marshall Space Flight Center is an integral part of the Engineering Directorate.

National Aeronautics and Space Administration

Materials Diagnostics Laboratory



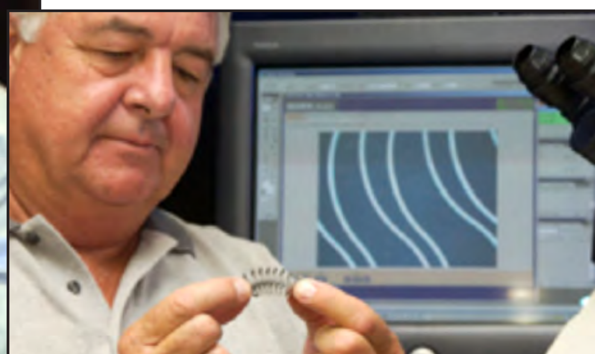
EM31 Failure Analysis and Metallurgy Branch

The EM31 Failure Analysis and Metallurgy Branch provides world-class support for materials design, development, characterization, and constituent hardware failure analysis. EM31 helps solve materials design issues, fosters manufacturing process optimizations, creates new materials when existing systems are inadequate, and helps rectify component life cycle service issues when failures occur.

The development and operation of both simple and complex engineering components requires the integration of recognized materials categories with known or developing manufacturing processes. Today's cutting-edge engineering systems operate under extreme conditions that exceed the known performance envelope of many materials. To ensure system safety and effectiveness, some hardware components must be analyzed to better understand materials degradation. Through bulk and surface chemical analysis, fractography, and microstructural analysis, EM31 scientists and engineers collect physical and chemical evidence of a material's performance. By incorporating this knowledge into new or existing systems, hardware reliability can be maximized and risk can be minimized.

EM31 Material Diagnostics Team

The EM31 Material Diagnostics Team, within the Failure Analysis and Metallurgy Branch, embodies a broad core of experience in materials as well as failure analysis. Qualitative and quantitative data on materials characteristics such as microstructure, bulk chemical composition, surface composition, crystal structure, and atomic configuration can be collected and coordinated with expert interpretation for any material, metallic or non-metallic. A comprehensive combination of modern analytical tools is utilized to provide complete understanding of material status, hence, that understanding can be extended to service performance.

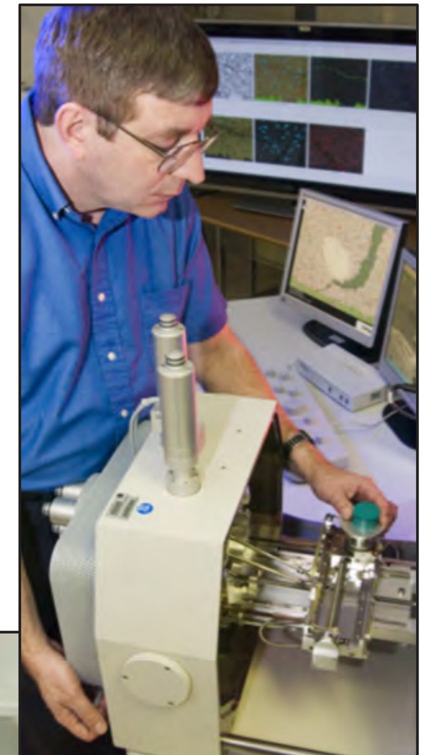


Sample Preparation

A fullservice materials sample preparation laboratory is available for sample sectioning, mounting, polishing, and etching to reveal microstructural features. Photography services are also available to record the initial shape and size of components before sectioning or mounting.

Microscopy Services

Comprehensive microscopy services are available including optical microscopy, stereomicroscopy, scanning electron microscopy (SEM), and transmission electron microscopy. All material types can be analyzed including metallic, ceramic, composite, geological, and biological. High-resolution images of surfaces and internal microstructures can be captured at magnifications up to 1,000,000 times. Bulk chemical analysis can be performed using energy dispersive and wavelength dispersive X-ray spectroscopy.



Surface Analysis Services

Surface chemistry can significantly affect material performance in areas such as lubricity and bonding.

In order to quantify surface chemistry within the outermost atomic layers, secondary ion mass spectroscopy (SIMS), electron spectroscopy for chemical analysis (ESCA), and auger electron spectroscopy (AES) are employed to determine elemental, isotopic, molecular, and chemical bonding information. SIMS can detect contamination down to parts per billion and document all elements, even hydrogen and lithium, which are relevant to aerospace materials. ESCA reveals both surface elemental information and bonding information that helps reveal the identity of surface compounds. AES provides high spatial resolution chemistry and morphology.

Materials Mechanical Test Facility (MMTF)

COMPUTER-CONTROLLED MECHANICAL TESTING, CORROSION RESEARCH, AND PRECISION PLATING FOR HIGH-PERFORMANCE AEROSPACE SYSTEMS

Mechanical Materials Testing & Corrosion Engineering

This mechanical materials test facility offers the largest scope of evaluation for stress and fracture issues under one roof at NASA. Materials performance is evaluated in extreme conditions using simulated in-process or service-induced heating/cooling/loading with computerized data acquisition. U.S. Government and industry specifications are supported for any standard test for axial tension-compression or corrosion. Custom tests are also designed and carried out, such as special component testing for simulated service loads and environments. Materials susceptibility to corrosion and stress corrosion cracking is studied, as well as hydrogen diffusion and entrapment. This facility is ISO 9001 certified, and consulting services are offered in all areas.

Mechanical Testing

Twenty mechanical test systems are used to apply force from 0.05 to 900 kN (0.01 to 200 kip) at temperatures from –268 to 1,093 °C (–450 to 2,000 °F) with computerized data acquisition. Tests are run in air and gaseous or liquid hydrogen, helium, and nitrogen, as well as in ambient aqueous salt baths.

Test capabilities include:

- Tension and compression
- Young's, tangent, chord, and shear modulus
- Stress rupture
- Bending and ductility of metals and welds
- Three- and four-point bend
- Plane-strain fracture toughness
- High/low cycle fatigue
- Crack growth rate (da/dN, da/dt)
- Crack-tip opening displacement
- Fracture toughness (J_{IC}, K_{IC}, K_{IEAC})
- Hardness
- Simulated service
- Torsion testing of fasteners
- Photostress strain measurements

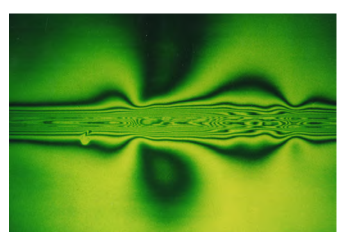
Corrosion Research

Investigations are made of material susceptibility to corrosion and stress corrosion cracking, along with protective coating and sealant performance. Accelerated test methods are used to evaluate corrosion rates, as well as hydrogen diffusion and entrapment. These techniques include electrochemical impedance spectroscopy and Tafel, linear, and cyclic polarization.

Precision Plating

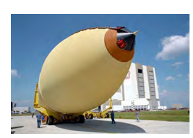
Plating is performed on a small scale for electrolytic and electroless nickel and nickel alloys, as well as electrolytic copper. Research and development are conducted to assist scientists and engineers whose projects may benefit from plating and electropolishing. Consulting services are available for plating and surface treatment issues.

Surface crack tension sample



Weld photostress measurements

Polarizing filter for photostress measurements



Super lightweight External Tank

Materials Engineering Core Capabilities

8-40453
FL-2005-06-95-MSFC

ESSSA Industry Day Tour

Materials and Processes Laboratory
Building 4707

Composite Manufacturing
Digital Manufacturing
Rapid Prototyping
Tool Crib

Marshall Space Flight Center
Materials and Processes Laboratory

NDE Inspection of
Spin-formed dome

Full-scale Process Development and Manufacturing Demonstration

7-axis machining center that converts
to a fiber-placement machine

20” autoclave

Machining of common
bulkhead structure

Composite crew module

Manufacturing modeling
and simulation

Management of NASA's National Center for Advanced Manufacturing (NCAM)

Principal Agency Asset For Advanced Manufacturing Development

- Located at MSFC and at the Michoud Assembly Facility (MAF) – Infrastructure Supports Small to Large-scale Developmental Thrusts
- Leverages Other Government Agencies, Industry, and Academia to Advance State of Manufacturing Technology
- Addressing Challenges in Digital Manufacturing, Supply Chain Management, Materials and Manufacturing Technology Readiness Levels

Marshall Space Flight Center
Materials and Processes Laboratory

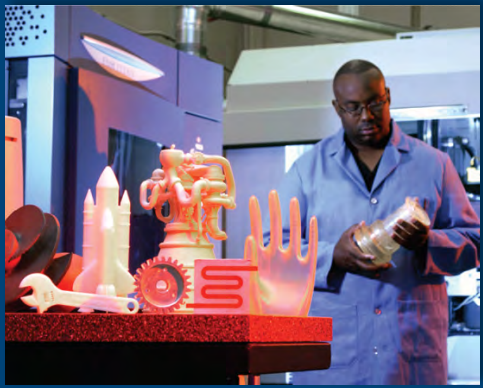
Management of NASA's National Center for Advanced Manufacturing (NCAM)

NCAM principal facility at MSFC, Building 4707

Subscale motor fabrication, MNASA

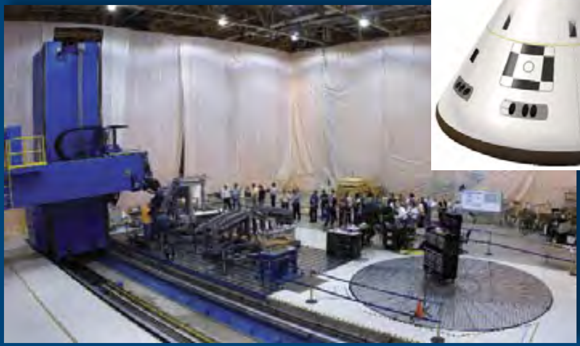
NCAM facility at MAF – large composite structures

Composite LH2 tank

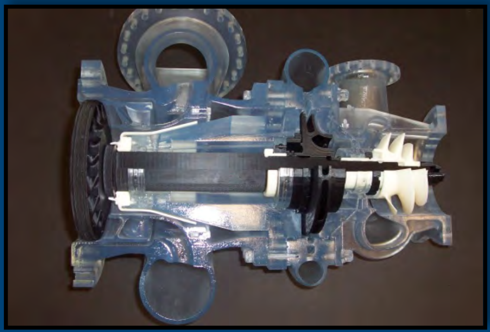


Rapid prototyping technology

NCAM facility at MAF – supporting Orion production



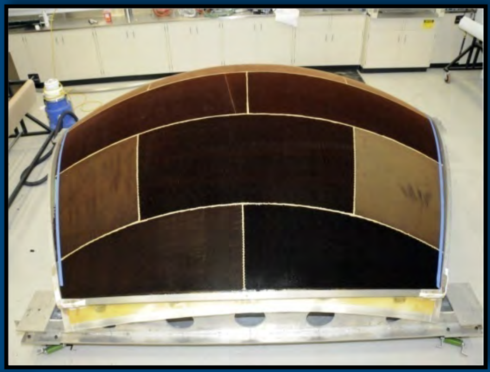
Marshall Space Flight Center
Materials and Processes Laboratory

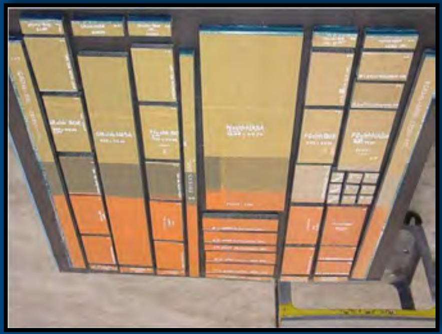


Rapid Prototyping technology

EM40 – Nonmetallic Materials and Manufacturing Division

- EM41 – Nonmetallic Materials Branch
  - High Temperature Materials Team
  - Polymeric Materials Team
- EM42 – Nonmetallic Manufacturing Branch
  - Advanced Processes and Digital Solutions Team
  - Composites Manufacturing Team
  - Advanced Manufacturing Technology Team





Complex composite structures

Marshall Space Flight Center
Materials and Processes Laboratory

EM40 – The Nonmetallic Materials and Manufacturing Division utilizes state-of-the-art facilities in the National Center for Advanced Manufacturing (NCAM) to develop new and enabling technologies for space vehicles and propulsion systems. The primary focus of the division is to perform research and development (R&D) and to serve as a consulting, performing, and approving activity for relevant aspects of nonmetallic materials and manufacturing technology. Research and development efforts encompass the areas of advanced composites and bonded structures, thermal and cryogenic insulation, high temperature ablative materials, structural adhesives, rapid prototyping, process simulation and digital manufacturing, advanced ceramics and ceramic matrix composites, and environmentally-safe material replacements.

Projects/Programs Supported

- *Space Shuttle*
  - *Orbiter – NOAX crack repair material provided in support of every flight*
  - *External Tank – cryogenic insulation and associated application processes, flight composite nose cones fabricated in-house*
  - *Reusable Solid Rocket Booster – ablative thermal protection materials, nozzle materials, seals, adhesives, insulation and all associated processes, obsolescence issues*
- *Ares I*
  - *First Stage – similar support to that provided to Shuttle RSRB, plus structural composite materials in the frustum*
  - *Upper Stage – responsible for in-house development of TPS, Common Bulkhead, Composite Interstage and Systems Tunnel, and Digital Manufacturing (Model-based instructions and manufacturing execution systems) – <u>considerable</u> hands-on experience*
- *Orion Launch Abort System (LAS)*
  - *Considerable support on materials and processes for three solid motor systems*
  - *Focused support on composite motor cases and other composite structures*

Composite Fabrication Process Development

MSFC has extensive experience developing processes to fabricate lightweight composite structures. Our facilities allow for a wide variety of composite projects both automated and hand lay-up, with parts ranging in use from process development through demonstration and on to flight hardware. Facilities available include: filament winding, fiber placement, tape laying, automated cutting tables, large–scale machining, tape wrapping, cold storage for materials, autoclave, and large oven.

ET Composite
Nose Cone

ACT Manufacturing Process
Development

60K Fastrack combustion
chamber and nozzle

Large Composite Tank Structures

MSFC has extensive experience and expertise with the development of large composite tank structures. The composite manufacturing area contains fiber-placement machines, filament winders, ovens and large autoclaves that are used for these structures. There are also unique large-scale test facilities that are utilized for structural tests and propellant loading of the vessels in a flight-like environment. This expertise is also supported by expert personnel with experience in NDE and damage tolerance. MSFC also has world-class materials testing facilities.

6' diameter composite tank fabricated at MSFC with Northrop Grumman and was tested successfully with liquid hydrogen

4.5' diameter composite tank fabricated at MSFC with Lockheed Martin and was tested successfully with liquid Oxygen

Composite over-wrapped pressure vessels (COPVs)

MSFC has a complete state-of-the-art facility for the development of composite over-wrapped pressure vessels. Many vessels have been produced that were included in the development of new advanced propulsion systems. COPVs have been developed that were part of a multi-NASA center effort to produce ultra-light vessels for launch vehicles and spacecraft. COPVs have been developed under partnerships with industry in NASA and DOD development efforts.

Filament winding of an advanced composite over-wrapped pressure vessel

ESSSA Industry Day Tour

Materials and Processes Laboratory
Building 4755

Metal Joining (Friction Stir-Welding)

EM32 Metal Joining and Processes Branch

The Metal Joining and Processes Branch specializes in the selection, development, and application of materials and processes for a wide range of NASA, Aerospace, Defense, and Industry programs. Responsibilities include developing manufacturing techniques for small to large scale metallic components using traditional and advanced processes such as spin forming, forging, rolling, casting, powder metallurgy, and vacuum plasma spray. EM32 also specializes in all metallic joining processes such as, friction stir, ultrasonic, variable polarity plasma arc, tungsten inert gas, electron beam welding, and brazing. Engineers routinely characterize commercially available materials using standard techniques and testing in specialized environments. New materials and processes are also developed to fill special needs or to improve performance. The Branch has significant experience with the processing and characterization of aluminum structures, advanced copper based alloys, titanium alloys, superalloys, metal matrix composites (MMC's), refractory metals, and other high temperature metal carbide materials. Engineers have developed special experimental techniques and analyses to evaluate the performance of materials. The work includes extensive material property testing, development of process/property relationships, and fabrication of prototypic components and structures.

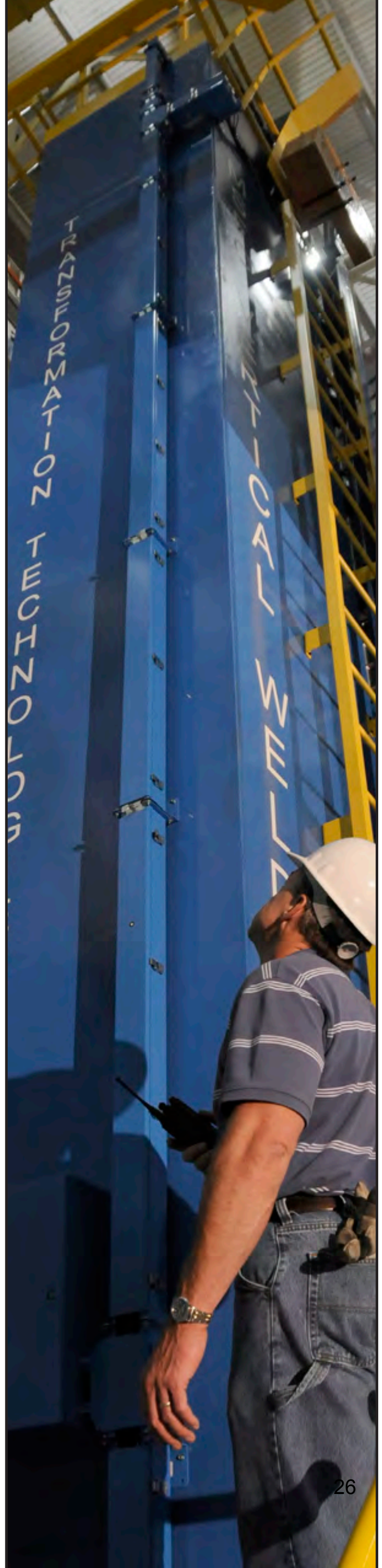
Welding and Manufacturing Team

The Welding and Manufacturing Team is responsible for developing metal joining and manufacturing processes for a wide variety of applications including large propellant tanks and primary vehicle structures. The EM32 Advanced Weld Process Development Laboratory is part of the National Center for Advanced Manufacturing (NCAM) at MSFC. The Laboratory was developed specifically to support the Space Shuttle's external tank and later the International Space Station's manufacturing programs. During the 1980's and early 1990's, MSFC led the development of the first variable polarity welding systems. MSFC also developed and patented a plasma welding torch that was used for External Tank production and is still widely used in launch vehicle industry today. Engineers at MSFC have since matured the Friction Stir Welding process to full implementation in External Tank production. Most recently, a Self Reacting Friction Stir Welding (SR-FSW) Process was developed at MSFC to allow Friction Stir Welding without the need for a backing anvil. Friction Pull Plug Welding (FPPW) was also developed to perform close-out of SR-FSW welds. EM32 Engineers specialize in the optimization of advanced joining processes and transfer of the technologies from laboratory scale to flight hardware including full scale manufacturing of very large complex structures. Experimental techniques include design of experiments, parameter bounding, and worst case weld joint evaluations to fully optimize and verify processing requirements. EM32 weld engineers are widely known for their expertise and participate in the development of national welding standards.

MSFC Advanced Weld Process Development Laboratory

Friction stir welding of dome gores on the universal Robotic Weld Tool (RWT)

Friction Stir Welding of Barrels Panels
on the Vertical Weld Tool (VWT)



Capabilities and Facilities:

- 70,000 square feet of manufacturing space including major high bays capable of accommodating the assembly of full-scale launch vehicle structures.
- 7 operational Friction Stir Welding Systems that can accommodate small-scale process development up to full-scale assembly. Systems include the Vertical Weld Tool for assembly of 40 foot-diameter barrel sections up to 25-feet tall and the Robotic Weld Tool for complex-curvature weldments up to 36-feet in diameter and 22.5-feet tall.
- Welding capabilities includes 4 plug welding systems, 2 VPPA fusion welding systems, manual fusion welding systems, and a machine shop to support welding and manufacturing process development.
- Thermal stir welding (TSW) to address new challenges in the solid state joining of high melting temperature alloys such as titanium and Haynes alloys.
- Significant experience with alloy selection and procedure development for brazing applications. Complex brazing procedures have been developed for joining heat exchangers to high temperature heat-pipe cooled nuclear reactors. Capabilities include 2 hand held laser brazing systems that were developed for in-situ repair of nozzle cooling tubes on the Space Shuttle Main Engine. The systems are highly portable and can be used to perform very precise, localized braze alloy placement in field applications.

- Laser and Electron Beam welding techniques have been developed for manufacturing flight hardware components ECLSS and ISS. EM32 Engineers supported procedure development and qualification for the hardware, which was manufactured and welded in-house at MSFC.
- Weld analytical modeling tools have been developed and used extensively to solved process anomalies and push the state-of-the-art for advanced joining techniques. A fundamental understanding of the basic material and thermal engineering principles has allowed MSFC to develop physical and kinematic models of welding processes.
- In-house design, development, and manufacturing of Friction Stir and Friction Pull Plug welding systems. The capability provides a unique expertise and ability to quickly adapt and apply lessons learned during process development.
- Integrated Software and Controls Team for developing and maintaining the advanced control systems that drive the welding tools and fixtures. The Team has developed and implemented extremely complex Friction Stir Welding control systems and has integrated the controls architecture into 5 systems at MSFC

- Extensive experience developing tooling and fixtures for large-scale, high-value, manufacturing projects. Designed and manufactured (in-house) the full-scale tooling and fixtures that were used to assemble 18-foot diameter hardware for the Ares I Upper Stage.
- Application of Nondestructive Examination (NDE) inspection processes including dye penetrant, film radiography, ultrasonic, and visual techniques. Currently evaluating new NDE advancements such as phased array ultrasonic testing, eddy current, and digital X-ray.
- Cross-disciplinary, vehicle-level manufacturing planning for optimizing flows, facility utilization plans and requirements, tooling concepts, and cost estimates. Responsible for the Ares I and Ares V launch vehicle planning at the NASA Michoud Assembly Facility.

Thermal Stir Weld (TSW) system at MSFC

Materials and Processes Laboratory
Building 4765

Thermal Protection Spray Facility

4765 TPS Development Facility

- $10M investment in the 4765 TPS Development Facility

- State-of-the art features/capabilities:
  - 30'x30'x85' Class I Div I* temperature and humidity controlled spray booth with associated HVAC equipment. Provides:
    - 20'x27'x70' hardware capability
    - Temperature limits of 65ºF to 130ºF and temperature dependent relative humidity ranges of 5% to 75%
    - Ability to spray both cryoinsulation and primer material systems (first time capabilities have been combined at MSFC)
  - 2-part foam dispense system along with a nitrogen drum pressurization capability
  - 9-axis robotic application system with tower and track
  - Data acquisition and remote viewing capability
  - Cold-storage coolers required for processing of HFC-245fa based materials

4765 Robot, Track, and Tower

4765 Spray Booth

4765 Foam Dispense Unit

* Class I Div I rating allows use of flammable materials. Significantly increases cost of facility

TPS Tooling Capabilities

- TPS Transporter system provides mobility for the Vertical and Horizontal Processing Fixtures.

Status = Received

- Vertical Processing Fixture allows for vertically oriented cryoinsulation and primer process development. This tooling was designed to support Upper Stage Instrument Unit, Aft Skirt, and Interstage TPS processing development tasks.

Status = In Final Assembly

- Modified the MDA barrel for TPS process development activities by adding upper and lower bolting flanges and attached a seal plate to top end. (Note: Receiving a removable dome to attach in place of the seal plate as required.)

Status = Received

- Scissor Lift to support operations.

Status = Received

- Heated test panel fixture to hold multiple test panels during cryoinsulation and primer spray trials.

Status = Received

TPS Transporter

Vertical Processing Fixture (with MDA barrel)

Scissor Lift

Heated Test Panel Fixture

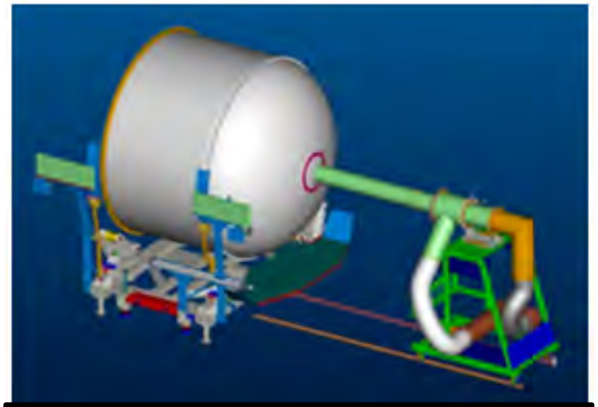
TPS Tooling Capabilities (contd.)

- Horizontal Processing Fixture allows for horizontally oriented cryoinsulation and primer process development. This tooling was designed to support Upper Stage LH2 tank, Common Bulkhead, LOX tank, and flange closeout TPS processing development tasks.

Status: In Final Assembly

- Rotary joint/stinger cart allows for heated air entry and exit through a single opening while maintaining rotational capability for the Horizontal Processing Fixture

Status: Received



Horizontal Processing Fixture (Rotary Joint/Stinger Cart shown at right)

Rotary Joint / Stinger Cart

ESSSA Industry Day Tour

Propulsion Systems Department

Building 4205

Nuclear Propulsion
Cryogenic Fluid Management (CFM)
Hardware-in-the-Loop, System Integration Laboratory (HIL-SIL)
Thrust Vector Control Research, Development and Qualification Laboratory (TVC)

Nuclear Propulsion

Space Nuclear Activities at NASA MSFC

NASA Marshall Space Flight Center (MSFC) is working closely with other NASA Centers, the Department of Energy (DOE), DOE National Laboratories, universities, industry, and others to help enable the next generation of safe, useful, and affordable space nuclear systems.

Fission Surface Power (FSP)

The current focus of NASA's space fission effort is Fission Surface Power (FSP). FSP systems could be used to provide power anytime, anywhere on the surface of the Moon or Mars. FSP systems could be used at locations away from the lunar poles or in permanently shaded regions, with no performance penalty. A potential reference 40 kWe option has been devised that is cost-competitive with alternatives while providing more power for less mass. The potential reference system is readily extensible for use on Mars. On Mars the system could be capable of operating through global dust storms and providing year-round power at any Martian latitude.

The FSP project is led by NASA Glenn Research Center (GRC). NASA MSFC is focused on non-nuclear testing and thermal simulators. FY08 activities at MSFC include integration of an Annular Linear Induction Pump (ALIP) into a pumped sodium potassium (NaK) loop (substantial testing at MSFC), integration of a Stirling engine into a pumped NaK loop (substantial testing at MSFC), coolant freeze/thaw testing, investigation of on-line coolant purification, thermal simulator development, and integration of a direct gas Brayton core simulator with a Brayton power conversion subsystem (significant testing at GRC).

Activities at MSFC are conducted at MSFC's Early Flight Fission Test Facility (EFF-TF). Activities are closely coordinated with other NASA Centers and DOE national laboratories. The ALIP that is undergoing test was provided by Idaho National Laboratory (INL). The Stirling engine and Brayton power conversion subsystem are being provided by NASA GRC. Oak Ridge National Laboratory (ORNL) provides insight related to coolant purification, materials, and other topics. Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL) assist with thermal simulator and experiment design and fabrication.

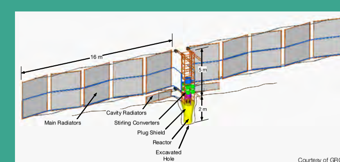
FSP-related activities at MSFC are helping reduce the technical and programmatic risk that would be associated with developing FSP systems. Work related to FSP systems may also help facilitate eventual development of in-space fission power systems.

Other Ongoing or Recent Space Nuclear Activities at MSFC

Radioisotope Power Systems (RPSs) have been used in space for nearly half a century. RPSs have enabled and may enable future exploration throughout the solar system.

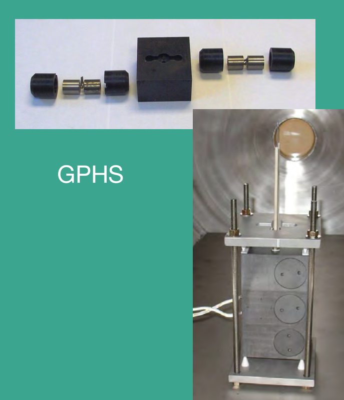
MSFC is performing a small amount of RPS-related work focused on developing highly realistic, non-nuclear thermal simulators to closely mimic a Pu-238 fueled general purpose heat source (GPHS) module. The work builds on thermal simulator development work previously performed at MSFC in support of the FSP project. High-fidelity GPHS thermal simulators could be useful in the development of advanced RPSs, or for investigating potential applications of RPSs.

Affordable, Power-rich Environment Anytime, Anywhere



Fission Surface Power System

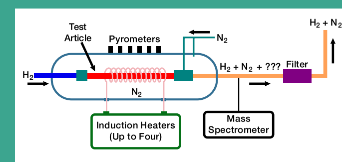
FSP Primary Test Circuit



GPHS

Nuclear Thermal Propulsion (NTP) systems can provide up to twice the specific impulse of chemical engines, and could enable extensive, affordable exploration of Mars and beyond.

MSFC has no FY08 funding for NTP work; however, work recently completed at MSFC could help enable the eventual development of NTP systems. Recent work included NTP system modeling, development of analytical tools, high-temperature materials research, and hot hydrogen testing. One potential early task in an NTP development program would be the evaluation of high-temperature fuels and materials. If an NTP development program was initiated, MSFC could assist through use of the Nuclear Thermal Rocket Element Environment Simulator (NTREES). NTREES could be used to test potential Nuclear Thermal Rocket fuel element materials and designs. NTREES is capable of testing single channels at prototypic temperatures and power densities using a hot hydrogen coolant. NTREES is designed to allow a larger power supply to be retrofitted, thus allowing larger test articles and elements to be tested.



NTREES Schematic

NTREES Fabrication

National Aeronautics and Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center
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www.nasa.gov

Pub 8–348554
FL–2008–01–07–MSFC

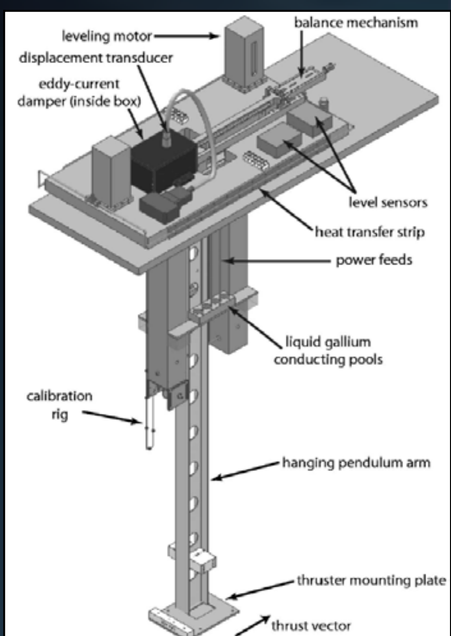
Electric Propulsion Research and Technology Development

Propulsion Systems Department

Electric Propulsion (EP) systems provide *high specific impulse*, saving on the propellant mass required for a given mission. The technology spans the range from mature, in-space thruster systems (200+ satellites) to advanced thruster development for far future applications

- **I_{sp} range**: 700 sec – 10,000+ sec
- **Thrust Range**: < 1 mN to 10's of N, depending on power level and thruster concept
- **Power**: <100 mW to >1 MW. Derived from solar (current) or nuclear (future)

The *low thrust* of current or implemented EP systems can only be measured using highly accurate and sensitive devices



Thrust Stand Schematic

MSFC developed *highly-sensitive thrust stand* for thrusts of 100 mN to 1 N (10 mlb to 0.1 lb), incorporating many unique features to improve the fidelity of the measurement. The stand has been used to directly measure the performance of several EP thrusters.

Princeton Cylindrical Hall Thrusters (pictured)

- Relatively low power (~100 W)
- Thrust levels: 1-10 mN
- Xenon propellant
- Novel cylindrical geometry reduces plasma losses to the walls of the thruster
- Applications include stationkeeping/orbit raising on small, power-limited satellites
- Multiple iterations tested at MSFC

Relevant Publications

1. "Thrust stand for electric propulsion performance evaluation," *Rev. Sci. Instrum.* (2006).
2. "Performance of a low-power cylindrical Hall thruster," *J. Propuls. Power* (2007).
3. "Performance of a permanent-magnet cylindrical Hall-effect thruster," *45th AIAA Joint Propulsion Conference* (2009).

Electric Propulsion Research and Technology Development

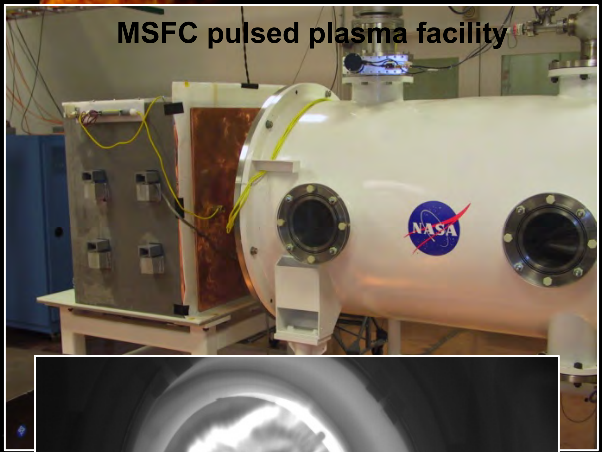
Propulsion Systems Department

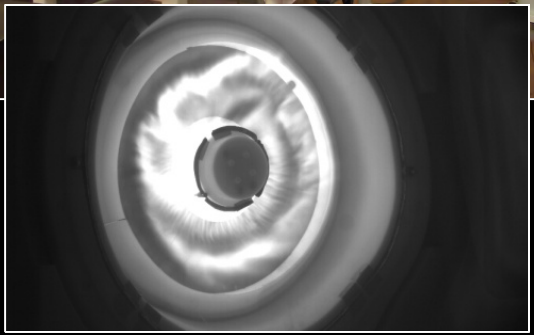
High Power (100 kW to >1 MW) electric propulsion (EP) systems provide relatively high thrust levels (1-10 N) and thrust densities (100s of N/m^2) at I_{sp} levels of 1,000-10,000 sec and efficiencies >50%.

MSFC has focused on two particular aspects of high power EP

- **Pulsed electromagnetic plasma thrusters**: Pulsing allows for low total power demands on a spacecraft while providing very high instantaneous power (MW-GW) during a short (1-10 ms) discharge
- **Liquid metal propellants**: Allow for high density propellant storage while potentially offering performance benefits over traditional

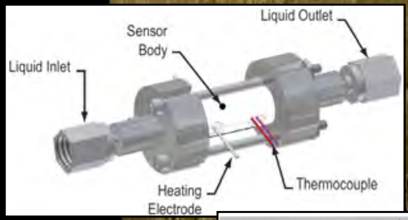
Pulsed Electromagnetic Thrusters





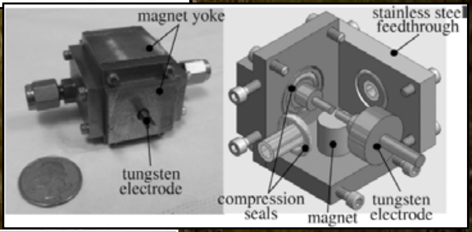
MSFC/Radiance 100 J/pulse FARAD thruster (1000-10,000 s I_{sp})

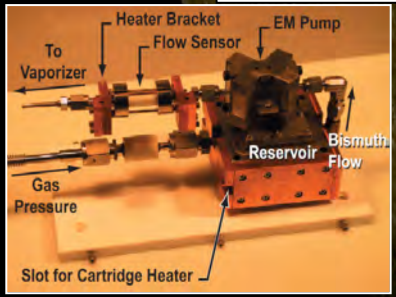
Liquid Metal Propellant Feed Systems and Thrusters



'Hotspot' bismuth flow sensor (MSFC patent)

Electromagnetic lithium pump



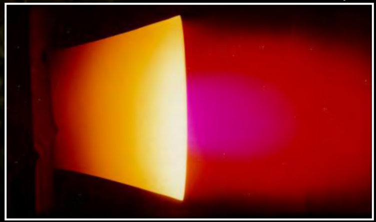


Bismuth liquid metal feed system

TsNIIMASH 160 kW$_e$ bismuth Hall thruster (8000 s I_{sp})

Lead Partner: Jet Propulsion Lab

MAI 200 kW$_e$ lithium MPD thruster (1000-3000 s I_{sp})



Lead Partner: Princeton University

Cryogenic Fluid Management (CFM)

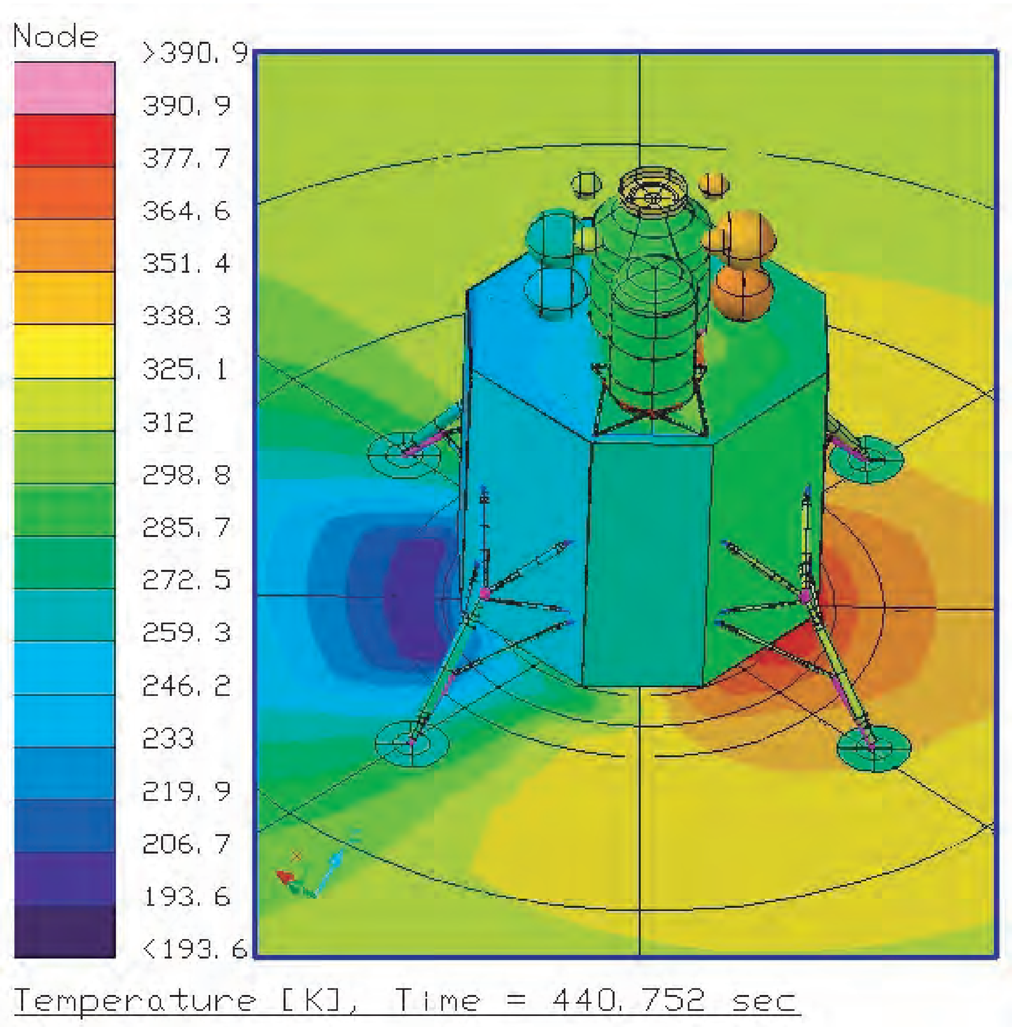
CFM

CRYOGENIC FLUID MANAGEMENT

MARSHALL SPACE FLIGHT CENTER

Cryogenic Fluid Management involves the **development** of **innovative systems** that address a wide range of technical issues associated with cryogenic fuels in low gravity. Team members develop systems that control the **pressure** and **temperature** of **fuel tanks**, ensure the fuel is properly fed into the engine, and monitor the level in the tank.

PROCESS



Conceptualize Identify and develop leading-edge technologies for future use in CFM systems and components.

Analyze Generate and deploy state-of-art computational tools to analyze preliminary designs.

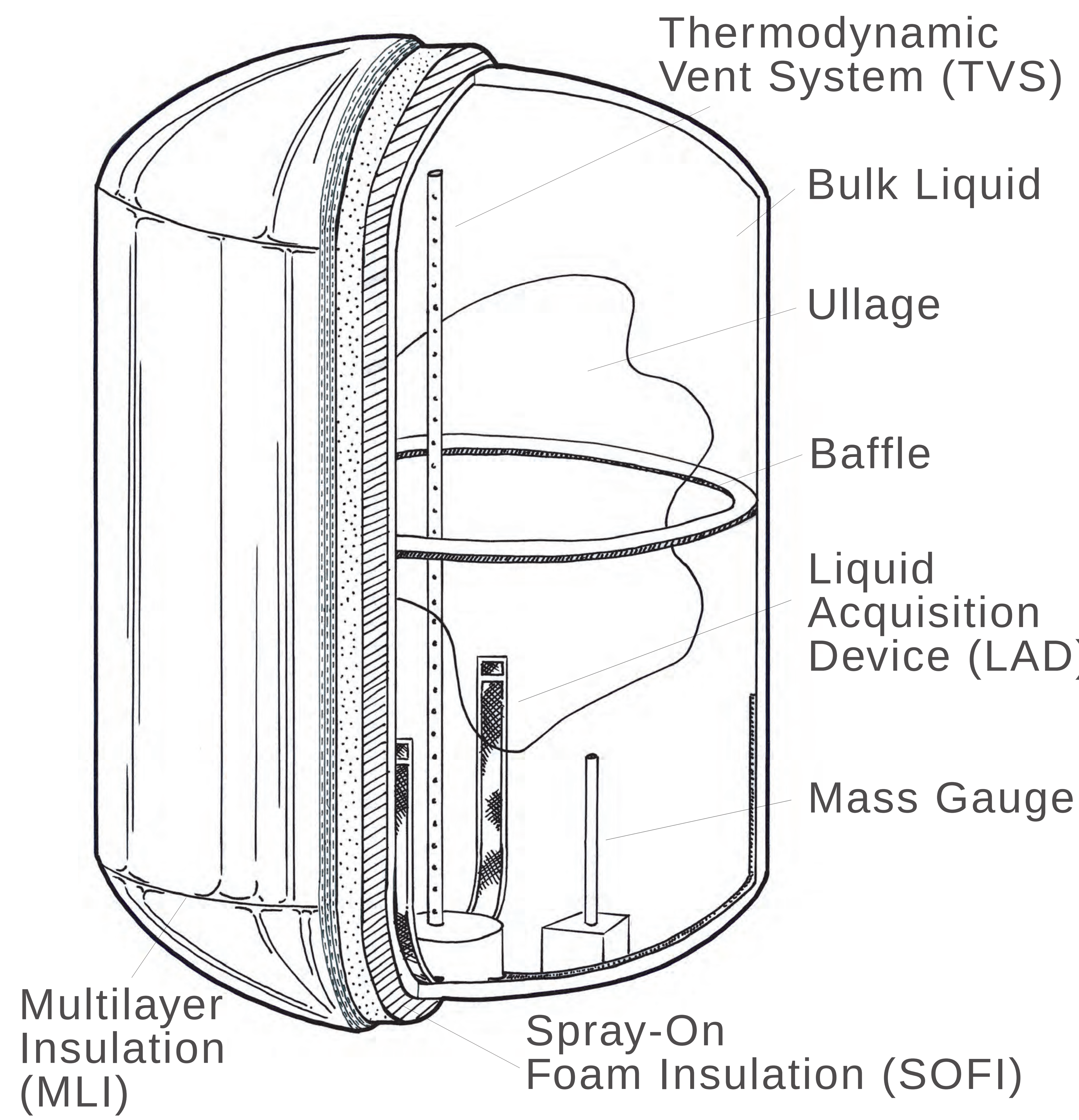
Design Develop CFM components into systems that effectively and efficiently surpass customer application requirements.

Integrate Negotiate the issues associated with merging subsystems into an operational CFM system.

Fabricate Utilize state-of-art production facilities to develop flightlike prototypes and hardware.

Test Execute simulations and experiments that aid in validation and verification of new designs.

FUNCTION



Elements of CFM

Exploration Systems Test Facility

- NASA MSFC Propulsion Research and Development Laboratory (Bld. 4205/Rm. 108)
- 9 ft diameter by 20 ft long vacuum chamber (10^{-8} torr)
- Pumps: 1 roughing (Kinny-CB7230), 2 turbos (TMG2400), 3 cryos (ADPSHD22)
- Electrical Supply: 240 kW DC power (16 supplies @ 150 V, 100 Amps)
- Cryogen Supply: Liquid Nitrogen (150 psig) with dedicated vent and drain lines
- Fluid Supply: Cooling water, Gaseous Nitrogen (4500 psig), Missile Air (3500 psig)
- Data Acquisition and Control via PC based LabVIEW
- ER24 - Propulsion Research and Technology Applications Branch

CRYOTE Ground Test at MSFC / PRDL

- Receive, install, test CRYOTE Ground Test Article (GTA) at MSFC PRDL
- Test time ~ 3 months, with 1 month prep and 1 month reporting bookends.
- Produce Flight Sequence Table for CRYOTE flight
- Validate analytical models for later use in flight CRYOTE designs
- Test Procedure
  - Chill facility liquid nitrogen supply to final valve
  - Evacuate CRYOTE – perform No-Vent fill cycle: "charge -> vent -> repeat -> fill when ready"
  - Measure heat leak by measuring boil off vapor with test article pressure held constant
  - Assess performance of Thermodynamic Vent System
  - Assess performance of Vapor Cooled Structure
  - Assess performance of Multi-Layer Insulation
  - Assess performance of Cryotracker
- Iterate test procedure details until flight sequence table is achieved.
- **Goal: Fully autonomous operation. Facility chills itself, then executes no-vent fill of CRYOTE GTA without intervention to demonstrate flight-like sequencing and operation.**

Photo courtesy of Mark Wollen at IES

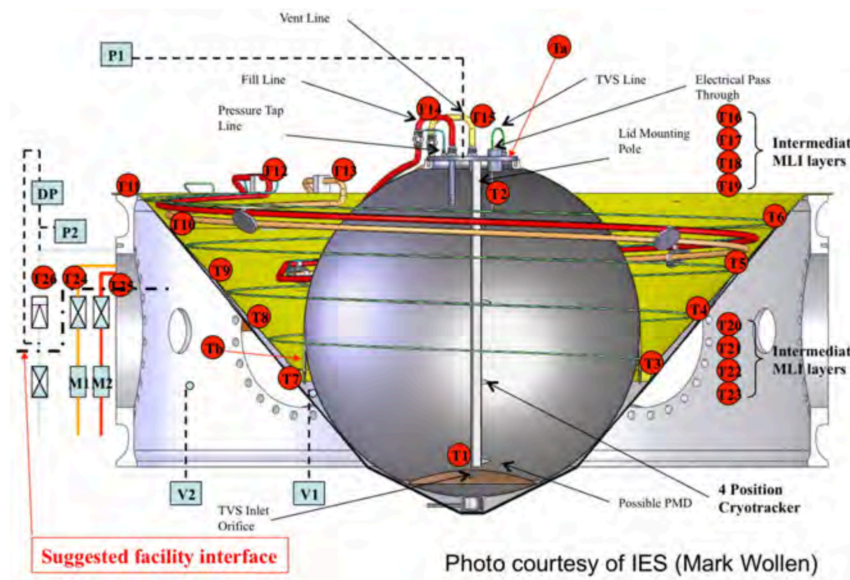


Photo courtesy of IES (Mark Wollen)

Hardware-in-the-Loop, System Integration Laboratory (HIL-SIL)

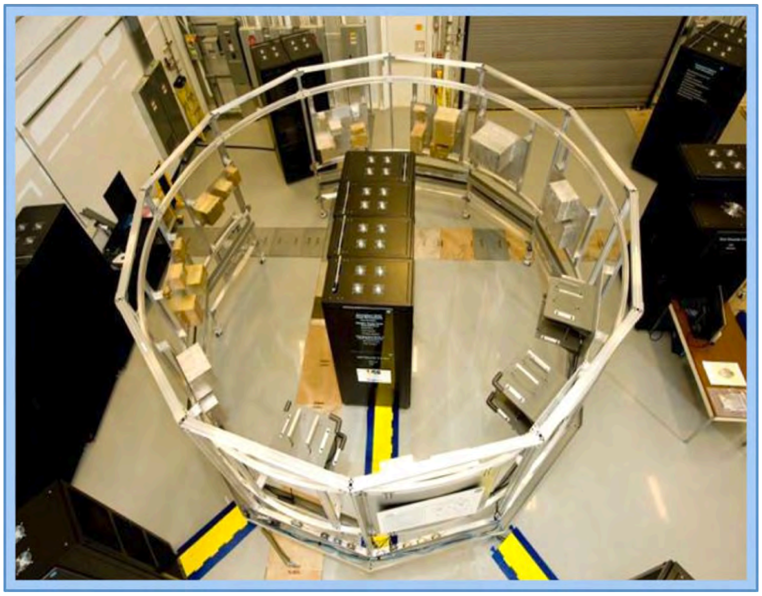
Marshall Space Flight Center

Avionics and Software Hardware in the Loop Facility

State-of-the-Art

Modular and Flexible

Easily Upgradeable



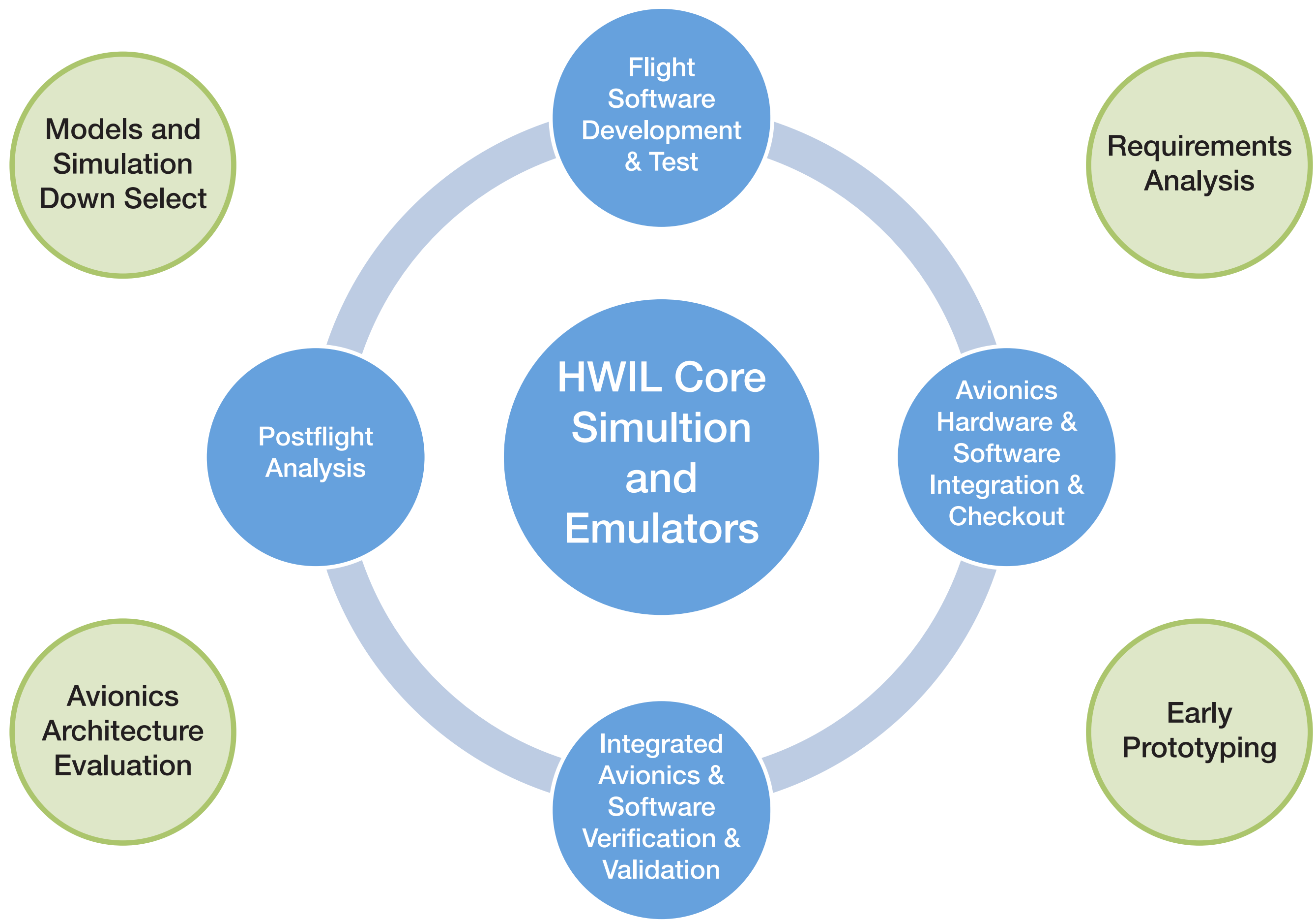
Overview and Capabilities

The Marshall Space Flight Center (MSFC) Avionics and Software Hardware in the Loop (HWIL) facility is a groundbreaking facility that allows engineers to test software with hardware to fully simulate the integration of systems prior to hardware manufacturing and test flight. It also creates an end-to-end simulation environment (real time/non-real time) supporting risk reduction, identifying and correcting defects, and improving cost and schedule factors throughout the program/project life cycle.

The Avionics and Software HWIL facility is comprised of the following:

- A core simulation (including subsystem and component models and models for flexible vehicle dynamics, rigid body dynamics, aerodynamics, environments and slosh), subsystem models, component models, input/output (I/O), sync infrastructure, and hardware used to communicate with flight-like avionics and flight software.
- A suite of models, simulations, and hardware interfaces capable of stimulating hardware and software through all mission phases.
- An automation environment that configures and controls the test operations, sets up test configurations, and executes and monitors test scenarios.

The facility design features that support flight software development and test, end-to-end avionics and software integration; check-out, verification, and validation of the integrated subsystem, and post-flight analysis and validation of vehicle performance.



Some of the key capabilities are illustrated in the diagram above. Flight software development and test and some integration and checkout of the avionics and software sub-systems have been successfully demonstrated on numerous occasions.

Formal verification and validation of end-to-end integrated avionics and software are currently planned as future and ongoing activities, while postflight analysis will only take place after a launch vehicle's first flight.

Other potential uses as denoted by the green or non-connecting circles in the diagram for this state of the art facility include, but are not limited to, requirements analysis, models and simulation down select, avionics architecture evaluation and early prototyping.

In addition, this platform fosters opportunities for development and evaluation of a variety of avionics architecture approaches for high-speed communication databus study, bus timing analyses, and early evaluation of vendor designs/breadboards.

Other aspects of vehicle avionics and software functionality (including guidance, navigation and control algorithms; and fault and redundancy management techniques) could be developed and validated, ultimately defining a paramount yet independent evaluation facility for the agency.

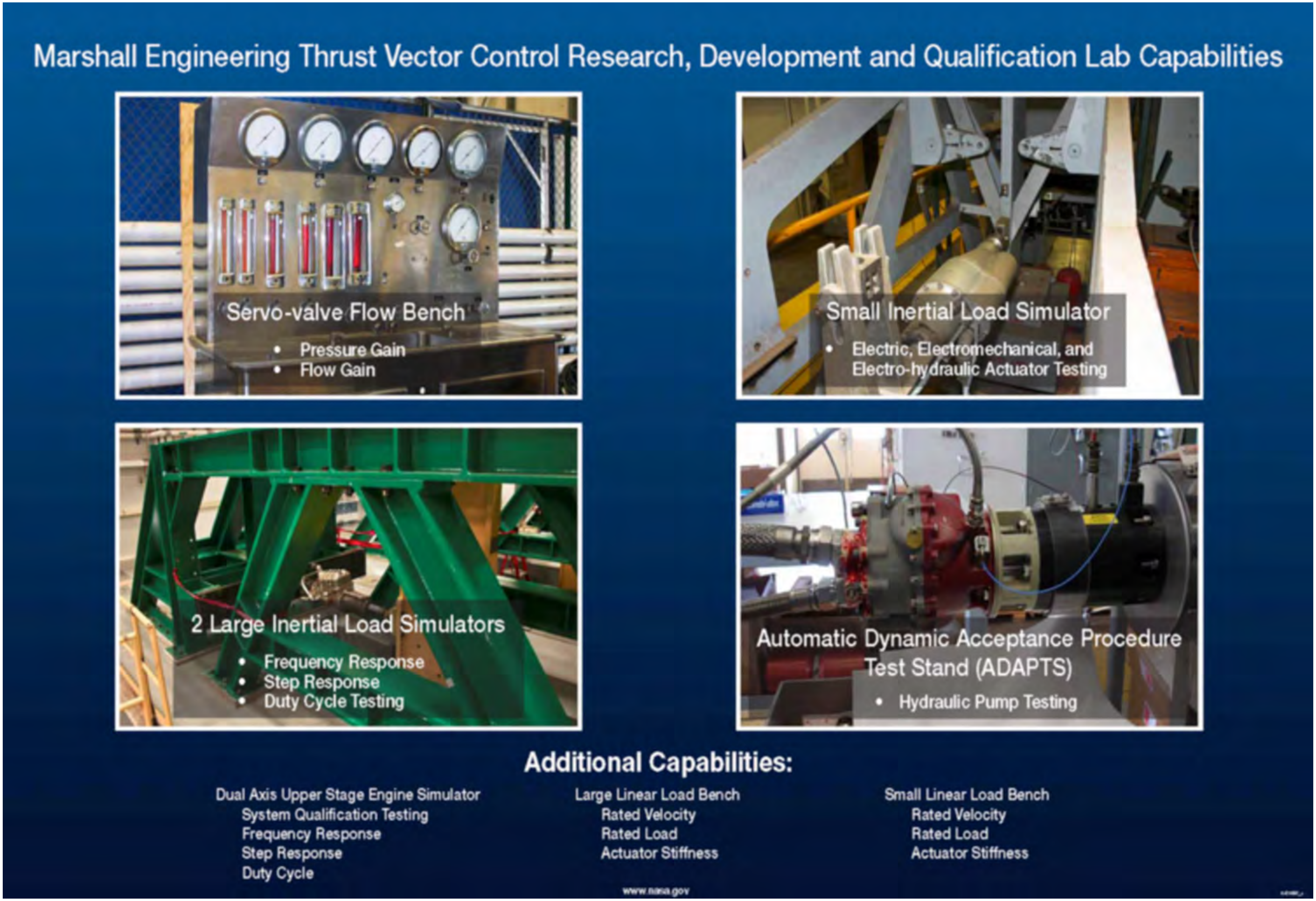
Thrust Vector Control Research, Development and Qualification Laboratory (TVC)

Thrust Vector Controls Laboratory

Building 4205 Room 110

- Hydraulic/Electric Actuator Testing
    - Inertial Load Simulators
    - Linear Load Bench - Static/Dynamic Load
    - Flexible Testing Capabilities for a Wide Range of Actuator Sizes
    - Variable Flow Hydraulic Power Supply Provides Flow up to 500 gpm at 3,000 psi
    - 300 volt, 90 kW Variable Electric Power Supply capable of delivering up to 300 amps
    - 300VDC, 11 Amp, 1.1 Amp Hours Li-Ion Battery Modules
- Data Acquisition and Control System
    - Actuator Control System
    - Avionics System Testing
    - Host to 3rd Party Actuator Controllers
    - High-Speed Data Collection
    - Flexible System Built with National Instruments Hardware and LabView Software

- Capability to Support Development, Qualification and Acceptance Testing



ESSSA Industry Day Tour

Other Facilities Information for Reference

Test Laboratory

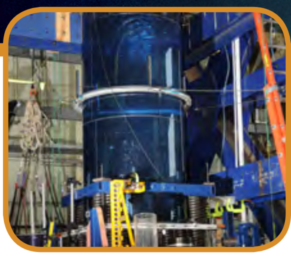
Propulsion Systems Department Component Development Area (CDA)

ESSSA Industry Day Tour

Test Laboratory

National Aeronautics and Space Administration

Marshall Space Flight Center
Test Laboratory





Engineering Solutions for Space Science and Exploration

Marshall's Test Lab

encompasses a wide range of specialized capabilities that NASA uses to conduct testing for space flight hardware research, development, qualification, acceptance, and anomaly resolution. Test Lab's 50-year experience base is a foundational piece of the Agency's investment in safely conducting the most challenging human and scientific missions ever performed.

Test Lab has partnered with the Department of Defense, academia, and industry to leverage its unique facilities and services. From computer model validation, to development and qualification testing, data for engineering analyses leads to informed decisions and significant risk reduction.

Aerospace hardware anomaly resolution and long-term maintenance are two areas where Test Lab offers extensive databases and personnel with direct, hands-on experience to solve flight-critical questions.

Knowledgeable civil service and contractor workforce who operate Test Lab have more than 1,000 years of combined experience in highly specialized fields. With this comprehensive background, the Test Lab team evaluates mission needs and develops methods to achieve critical test objectives and deliver vital test data.

Test Lab facilities accommodate test articles at any technology readiness level and comply with ISO9001/AS9100, OSHA VPP, and ISO 14001. The team has years of demonstrated reliability and safe operations, with physical security provided by the U.S. Army Redstone Arsenal and NASA. Marshall's Test Lab is conveniently located near major transportation lines.

While testing NASA's space hardware is Test Lab's main goal, the group also supports government agencies, industry, and others through Space Act Agreements and alternate contractual mechanisms.

Test Lab conducts structural dynamics and propulsion testing, two examples of their many capabilities.

Capabilities

Propulsion

- Solid, liquid, and hybrid propellant test capabilities for component, scale model, and system level testing up to 7.5 million lb of thrust.
- Pressures & propellants include: LOx, LH_2, CH_4, and RP-1 and a Center-wide cross country systems for GN2, GH2, GHe, and missile-grade air.

Environmental Testing

- Material Environment Test Complex performs multiple-environments testing and material evaluation.
- 28 test chambers simulate extreme space environments, including thermal vacuum, humidity, altitude, cryogenic, and corrosion effects.
- The Aerodynamic Research Facility, an intermittent trisonic blow-down wind tunnel, tests subscale models for vehicle designs.

Structural Strength

- Tensile test machines for structures (up to 25 feet) verify strength to 3M lbf.
- Hazardous structural test bay, used with reaction structures is rated for 2.5M lbf.
- The cryogenic structural test stand accommodate test articles to 33 feet in diameter.

Structural Dynamics

- Vibration tests utilize 6 electromagnetic shakers (up to 40,000 lbf) and 3 amplifiers.
- Reverberation, progressive wave tube and anechoic chambers comprise the acoustic test facility.
- Experimental Modal Analysis includes full test capability from component level hardware to fully integrated flight vehicles.
- Fluid slosh testing and digital image correlation measurement techniques.

Other Services

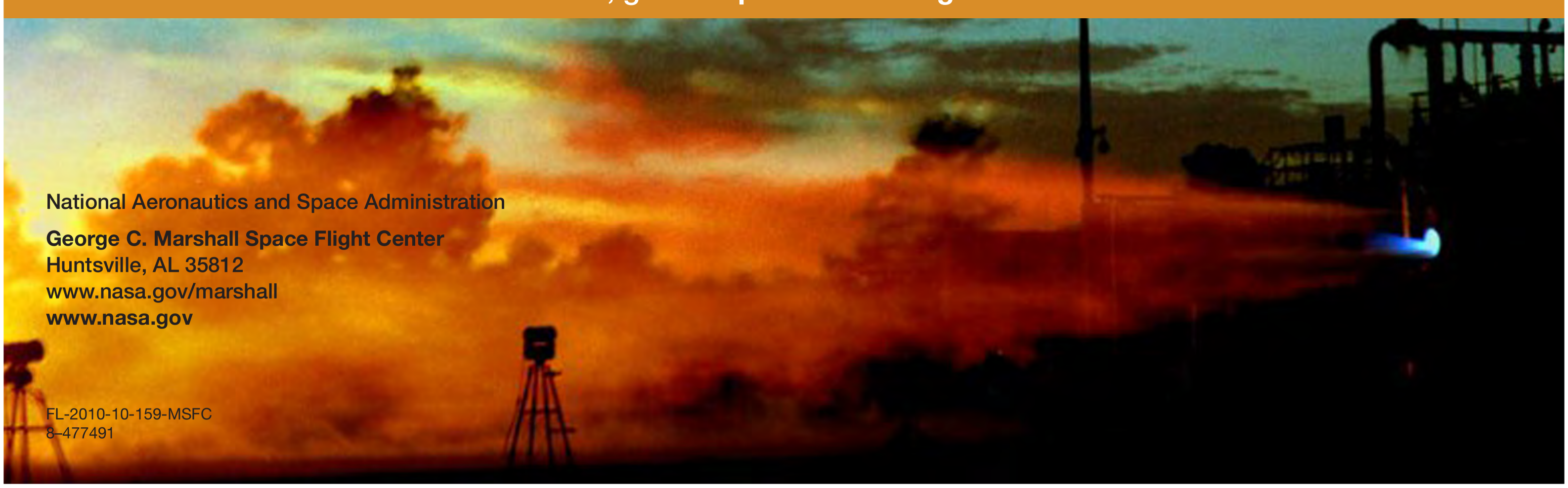
- Special Test Equipment design includes test stand design and modifications.
- Fabrication, valve lab, calibration facility, and handling crews are available in-house.
- High-speed photography and video supplement data acquisition technologies.

Test Lab assets range from one-of-a-kind to highly adaptable; supporting human-rated launch vehicle development, high technology science missions, and various industry programs.

Key Benefits

- Full life-cycle testing and evaluation capabilities from materials development and proof-of-concept articles up to qualification of integrated systems.
- Budget analysis and risk management available in-house.
- Workforce & facility flexibility are necessary to meet customer needs.

For more information, go to **http://www.nasa.gov/centers/marshall/**



National Aeronautics and Space Administration

George C. Marshall Space Flight Center
Huntsville, AL 35812
www.nasa.gov/marshall
www.nasa.gov

FL-2010-10-159-MSFC
8-477491

Propulsion Systems Department
Component Development Area (CDA)

Valves, Actuators, and Ducts Design and Development Branch (ER33)
Component Development Area (CDA)

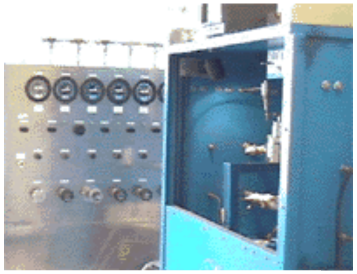
- **CDA**
  - Provide low-cost, rapid turnaround propulsion component and systems test, inspection, and repair services
- **Test Capabilities**
  - Flow testing
    - GN2 to 5000 psig; -320 to 850 degrees F
    - GHe to 5,000 psig; -300 to 850 degrees F
    - LN2 to 5,000 psig; -321 degrees F
    - LO2 to 550 psig; -297 degrees F
    - Methane to 550 psig
    - De-ionized water to 5000 psig; 70 to 175 degrees F
  - Hydrostatic testing to 30,000 psig
  - Leak, proof, burst testing
  - Electrical function testing; up to 300 V and 300 A
- **Equipment and Test Cells**
  - Two outdoor 10'x10'x10' explosion proof test cells (11 lbs TNT equivalent blast capability)
  - Indoor explosion proof valve test chamber with cryogenic bath (~ 4'x4'x4')
  - Thruster hot-fire test cell (100 lbs Thrust; 100,000 ft altitude)
  - Hot gas flow test cell
  - Environmental test chamber
  - Small vacuum chamber
  - Water flow bench
  - Water Flow Loop (200 GPM; to 2000 psig)
  - High & low speed Data Acquisition Systems (100+ channels)
  - Diagnostic and inspection equipment
  - Test support fabrication tooling & machinery
  - Weld shop (includes ASME B31 Code Certification)

Component Development Area Blast Cell

S-IVB Vent/Relief Valve Testing

RoCS SDTA Installed in Bunker

Advanced Fuel Turbine Bypass Hot Gas Flow Test



Valve Test Chamber

National Aeronautics and Space Administration

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www.nasa.gov/marshall

www.nasa.gov

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